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STUDY OF PASSENGER SUBJECTIVE RESPONSE TO IDEAL AND REAL-VEHICLE VIBRATION ENVIRONMENTS

By

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and

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CONTENTS

TABLES

FIGURE

STUDY OF PASSENGER SUBJECTIVE RESPONSE TO IDEAL AND REAL-VEHICLE VIBRATION ENVIRONMENTS

By

Raymond H. Kirby[1] and Peter J. Mikulka[2]

SUMMARY

The research conducted under research grant NGR 47-003-083 consisted of four research projects and a portion of a fifth. The initial studies undertaken had as their purpose defining the stimulus received by the subjects tested on the Passenger Ride Quality Apparatus (PRQA). Also, additional analyses on the data collected from field tests using buses, obtained from research conducted earlier in this research program, were conducted to better assess the relation between subjective ratings of ride quality and vibrations measured on the buses, and to better define the vibration stimulus measured in the field. Subsequently, research was conducted to establish the relation between subjective evaluation of the field tests using buses and simulations of these tests using the PRQA. Finally, the initial part of a series of tests aimed at developing a model describing the relation between the variables affecting ride quality was begun.

STIMULUS TRANSMISSIBILITY CHARACTERISTICS OF THE PRQA

The purpose of this study was to determine the relation between the stimulus, motion, and input to the PRQA and the stimulus recorded

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at the center of the seat while a subject was seated in the apparatus. Several frequencies, ranging from 0 to 30 Hz, were tested at each of three g-levels in both the vertical and lateral directions. Subjective evaluations of these stimuli on a satisfactory-unsatisfactory scale were also obtained.

Approximately 150 subjects were run in these tests and the results were reported in the Ride Quality Meeting held at Langley Research Center on February 25-26, 1974. The report of this study, authored by Jack D. Leatherwood[1], has been published by Langley Research Center.

SUBJECTIVE RATING OF RIDE QUALITY OBTAINED FROM FIELD TESTS USING TRANSIT BUSES

This research involved additional analyses of data collected under the report of project NAS1-9434-55. That research studied the use of several procedures for obtaining ratings of ride quality during field tests using transit buses. Re-analysis of the data was performed to more appropriately assess the relation between vibrations recorded on the buses and the ratings of subjects using the various rating procedures, to attempt to isolate the types of vibration more likely responsible for low ratings of ride quality, and to improve understanding of vibration stimuli experienced by the subjects while riding the buses. These analyses are included in this report as Appendix A.

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[1] Leatherwood, J.D., Vibration transmitted to human subjects through passenger seats and consideration of passenger comfort. NASA TN D-7929, April 1975.

RELATION OF SUBJECTIVE EVALUATION OF SIMULATIONS OF BUS RIDES PRODUCED BY THE PRQA WITH SUBJECTIVE EVALUATIONS OF THE ACTUAL BUS RIDES

The purpose of this study was to assess the capability of the PRQA as a simulation tool for determining meaningful subjective response evaluations of a bus ride. Although this experiment was part of the work to be conducted under NAS1-9434-57, the cost of the graduate student assistants and the latter half of data collection were borne by NGR 47-003-087. An account of this research is included in this report as Appendix B.

THE RELATIVE CONTRIBUTION OF THE SEAT AND FLOOR VIBRATION TO HUMAN COMFORT IN A SIMULATED AIRCRAFT RIDE ENVIRONMENT

The purpose of this research was: (1) to determine how ride discomfort varies as a function of frequency, amplitude, duration of exposure or any of the interactions among these; (2) to determine the relative contribution of the floor and the seat vibration to discomfort; and (3) to determine if equal discomfort curves can be obtained through ratings of vibration.

Eighty subjects were tested on this project and a report of this research has been prepared by Thomas K. Dempsey and Jack D. Leatherwood.[1]

[1] Dempsey, T.K., and Leatherwood, J.D. Methodological Considerations in the Study of Human Discomfort to Vibration. Presented at the International Conference on High-Speed Ground Transportation, Tempe, AZ, January 7-10, 1975.

DETERMINATION OF EQUAL-COMFORT CURVES THROUGH MAGNITUDE ESTIMATION

The purpose of this research is to determine the absolute threshold and equal discomfort curves as a function of frequency using the scaling method of magnitude estimation.

The research grant has provided sixty subjects for this project and with the remainder of the subjects to be provided by another grant.

APPENDIX A

SUBJECTIVE RATING OF RIDE QUALITY OBTAINED FROM FIELD TESTS USING TRANSIT BUSES

Mikulka, Kirby, and Simmons (1973) have used field tests with transit buses to study the extent to which subjective ratings using various rating procedures were correlated with various measuees of vibrations measured on the buses using power spectrum density analyses. Those data showed moderately high correlations using several of the rating procedures. It is suggested herein that these same data could have been analyzed to determine whether some types or combination of types of vibration are more probably responsible for ratings of poor ride quality. Such analyses could be useful in pointing the direction to more promising avenues of research.

The field tests in that study consisted of nine different bus rides over the same course to study subjective ratings produced by different scaling procedures. Seventeen segments of the ride, each lasting approximately 15 seconds, were selected for rating to cover the range of conditions found on the road course, and the subjects were asked to rate each of the segments. Data from four of these rides were chosen for the analyses reported in this paper; a ride using the five-point category estimation procedure, one using the magnitude estimation procedure, and two using a six-point category estimation procedure. As stated above, the correlations between each of these rating procedures and measures of the vibrations recorded on the buses was moderately high, generally around .50.

The previously reported analyses left two major avenues of data analysis unexplored: regression analysis and factor analysis. Regression analysis could be used to determine the multiple correlations between the subjective ratings on the buses and the various physical parameters of the vibrations, probably a more appropriate measure of the correlation between ratings and vibrations than was

used in the previous report. Regression analysis could also determine the relative importance combinations of axes and bandwidths of vibration for predicting the subjective ratings. Exploration with factor analysis could determine whether there is a meaningful organization of the physical parameters of vibration that might provide a better understanding of how the various physical parameters combine to affect the ride quality. This report is concerned with the results of these expanded analyses of certain of the previously reported data.

METHOD

Subjects

The subjects for the ride using the five-point category-estimation procedure were 26 undergraduate students recruited from the student body of Old Dominion University. The mean age was 22.8 years and the standard deviation was 6.2 years. For the ride using the magnitude estimation procedure, 20 subjects were used, 8 of whom were recruited from the student body of Old Dominion University and 12 who had never attended college. The mean age of these subjects was 18.5 years with a standard deviation of 2.6 years. For the first ride using the six-point category-estimation procedure 17 subjects were used, 7 of whom were recruited from the student body of Old Dominion University, and the remaining 10 who had never attended college. The mean age of this group was 18.9 years with a standard deviation of 3.67 years. The second ride using the six-point procedure used 26 college students, recruited from Old Dominion University; the mean age was 23.8 years and the standard deviation was 6.18 years.

Apparatus

A Virginia Transit Company bus was rented for use in this experiment and the company also provided a trained driver. Each bus was equipped with 39 seats but the subjects were only permitted to sit in the 31 seats that faced toward the front of the bus.

Vibration was measured using a Langley Research Center ride measurement package (Catherines, Clevenson, and Scholl, 1972). This instrument was located at forward and center locations of the bus floor, utilized servo accelerometers, and recorded on magnetic tape the vibrations in each of the three linear axes; longitudinal, lateral, and vertical. No angular accelerations were measured.

Procedure

Prior to boarding the bus, the subjects were instructed in a classroom as follows:

> May I have your attention please. From this point on, we would like you to consider yourselves subjects in an experiment dealing with "ride quality."
>
> Your part in this experiment will be threefold. (1) You will ride a bus over a preselected course for approximately 1 1/2 hours, (2) You will be asked to rate the ride quality you are receiving during 17 15-second segments of the bus ride, and (3) You will return here after the bus ride to fill out a short background information questionnaire. All information will remain anonymous, so your name need not appear on any of the forms.
>
> For each of the 17 segments to be rated, I will call for your attention over the public address system approximately 10 seconds prior to the beginning of a segment. I will give you a "begin" and a "stop" command for each segment and after this you will rate, on your rating scale, the quality of ride you received during the particular segment. Keep all your ratings confidential since only your own specific ratings will be of value.
>
> During the majority of the trip you will be allowed to do anything you desire (talk, read, etc.). Smoking will not be permitted. Moving from seat to seat will not be allowed, because the questionnaires and subjective rating scales are coded according to your location on the bus. Be sure the codes on your rating sheets and your background questionnaires match.

More specific questions concerning the experiment will be answered after the 3 parts of your duties are completed. Are there any questions?

Those subjects who were to use the five-point category estimation procedure were told,

For each of the 17 ride segments, you will be given a verbal signal to rate the ride quality of the particular segment. For each segment, you may rate the ride quality <u>excellent</u> by placing a number "5" in the proper blank, <u>good</u>, by placing a "4" in the blank, <u>fair</u>, by using a "3", <u>poor</u>, by marking with a "2", or <u>unacceptable</u>, by placing a number "1" in the blank. You will make 17 ratings; each will be rated with either a 1, 2, 3, 4, or 5. Remember, you are rating the ride quality of each ride segment. Are there any questions concerning this rating scale?

The subjects who were to use the magnitude estimation procedure were told,

For each of the 17 ride segments, you will be given a verbal signal to rate the ride quality of the particular segment. The first ride segment may be rated with any number you wish. This rating and all additional ratings will be your guide for any ratings which follow. That is, if the second ride segment has a better ride quality than the first, it will receive a higher rating. If it has a poorer ride quality than the first, it will receive a lower rating. If the ride quality of the two segments are the same, they will receive the same rating. You will make 17 ratings; each will be rated with a number (your choice) along a continuum with the highest number corresponding to the best ride quality and the lowest number corresponding to the poorest ride quality. Remember, you are rating the ride quality of each ride segment. Are there any questions concerning this rating scale?

The subjects who were to use the six-category estimation procedure were told,

> For each of the 17 ride segments you will be given a verbal signal to rate the quality of that particular segment. If the quality of the ride is satisfactory to you, place a "1" in the blank if it is very satisfactory, a "2" if it is moderately satisfactory, or a "3" if it is mildly satisfactory. If the quality of the ride is not satisfactory to you, place a "4" in the blank if it is mildly unsatisfactory, a "5" if it is moderately unsatisfactory, or "6" if it is very unsatisfactory. You will make 17 ratings; each will be rated with either a 1, 2, 3, 4, 5, or 6. Remember, you are rating the ride quality of each ride segment. Are there any questions concerning this rating scale?

The route chosen for the rides measured 50 miles and required approximately 1 1/2 hours to be traversed. The route was chosen to include a wide variety of the prevailing road conditions in the Norfolk-Virginia Beach area. Seventeen segments of the planned ride were selected for evaluation by the subject. Each of these was 15 seconds in duration and was separated from other segments by 5 to 10 minute intervals. These segments were chosen because of the varying conditions of vibration produced and because of the presence of a landmark that could be easily identified by the experimenters. During the actual test, the bus driver was instructed to maintain a constant speed while traversing the test segments. The subjects were alerted to approaching test segments and told when the segment began and ended. A loudspeaker was used by the experimenter to direct the subjects.

Vibration Measurement

The longitudinal (fore and aft), lateral (side to side), and vertical (up and down) accelerations were recorded on magnetic tape. The taped data were then analyzed through the LaRC Time Series Analysis Program to generate the power spectra associated with each axis and segment of vibration. The resultant power spectra were then utilized in a subroutine to calculate the total average

power (TAP) and the root mean square (rms) acceleration level in 2 Hertz (Hz) bandwidths ranging from 1 to 30 Hz. These vibration parameters for each segment of ride and for each axis of vibration were then used for correlation with the subjective responses.

RESULTS

The Physical Stimuli

The actual stimuli experienced by the subjects (the vibrations generated during the bus ride), were analyzed by the procedure described in the preceding section. The TAP data presented in table 1 shows the mean and standard deviation of the acceleration, taken across the 17 segments rated by the subjects, for the various frequency bandwidths in each of the three axes of linear vibration for each of the four rides. The greatest amount of energy was in the 13 to 15 Hz bandwidth, while the energy in the other frequency bands was distributed rather evenly about the 13 to 15 Hz band, although the lowest frequency of the vertical axis deviates from this pattern.

Regression Analysis

The data used for predictors in the regression analyses were the 36 measures of g(rms) of the physical stimulus, the energy in each of 12 frequency bandwidths for each of the three linear axes. The criterion variable chosen for this analysis was the individual subject's rating of each test segment. It is suggested that the mean of each group of subjects' ratings could have been chosen as an alternate criterion, and would possibly result in higher multiple correlation coefficients as well as higher simple correlations with the physical measures of vibration. However, the individual rating was chosen because it is the measure to which the predictive equation is to be applied ultimately.

Table 2 shows the simple correlation between the subjects' ratings and the 36 measures of vibration for each of the four rides. This table also shows the mean of these correlations and the corre-

Table 1. Table of PSD of vibrational stimuli.

	Scale	Axis	1-3	3-5	5-7	7-9	9-11	11-13	13-15	15-17	17-19	19-21	21-23	23-25
Mean	Five-point	V	4.11	.49	.94	1.73	3.50	5.01	12.70	1.11	1.00	.84	.60	.21
		L	.05	.19	.38	1.21	4.28	5.08	10.99	2.86	1.90	2.12	1.41	.80
		T	.06	.12	.20	.55	3.74	8.07	22.61	2.42	.57	.51	.42	.24
	Mag. Est.	V	5.33	.61	.82	1.74	3.31	4.18	12.71	.91	.94	.94	.62	.17
		L	.05	.16	.19	.48	1.50	1.03	1.95	.42	.40	.42	.21	.10
		T	.08	.12	.19	.38	3.17	5.01	14.57	1.57	.27	.19	.11	.07
	Six-point (7)	V	2.46	.68	.99	1.39	3.06	2.33	1.57	.61	.90	.76	.50	.23
		L	.03	.16	.37	.59	3.28	2.41	1.48	.43	.51	.76	.48	.34
		T	.10	.27	.52	.32	1.88	4.52	6.60	.68	.22	.19	.17	.11
	Six-point (8)	V	4.09	.58	.93	2.07	2.54	4.09	5.84	.76	.82	.86	.67	.17
		L	.04	.18	.24	.59	1.86	2.89	4.90	2.55	2.28	2.52	1.57	.82
		T	.07	.29	.66	.54	2.36	6.27	14.60	2.99	.90	.91	.54	.35
Standard Deviation	Five-point	V	2.56	.29	.59	1.43	3.56	4.56	13.54	.76	.59	.64	.45	.18
		L	.05	.14	.30	1.62	4.32	4.39	16.30	2.69	1.91	2.16	1.21	.64
		T	.04	.14	.23	.64	5.08	8.89	24.96	2.20	.53	.52	.36	.23
	Mag. Est.	V	6.27	.45	.62	1.30	3.09	3.01	13.55	.52	.55	.63	.46	.11
		L	.07	.14	.18	.36	1.18	.62	1.69	.29	.30	.34	.15	.07
		T	.06	.11	.21	.48	3.71	4.89	13.80	.98	.19	.15	.09	.13
	Six-point (7)	V	2.42	.81	.81	1.12	2.80	1.56	1.22	.60	.74	.67	.50	.20
		L	.04	.53	.66	.54	3.00	2.29	1.02	.34	.44	.74	.49	.37
		T	.57	.33	.51	.55	2.30	4.74	4.61	.49	.17	.19	.18	.09
	Six-point (2)	V	3.47	.53	.67	1.44	2.05	2.63	4.94	.35	.41	.43	.41	.09
		L	.05	.14	.14	.54	1.44	2.39	4.28	2.95	2.90	1.89	1.25	.57
		T	.05	.33	.62	.46	2.47	5.40	14.75	1.94	1.19	1.19	.66	.30

Table 2. Table of simple r with rating.

Scale	Axis	1-3	3-5	5-7	7-9	9-11	11-13	13-15	15-17	17-19	19-21	21-23	23-25	Mean	Total g(rms)
Five-point	V	.10	.32	.52	.51	.48	.52	-.09	.43	.55	.52	.51	.50	.41	
	L	.09	.05	.03	.33	.56	.25	.01	.39	.47	.46	.48	.38	.29	.35
	T	.40	.39	.38	.45	.45	.50	.03	.27	.46	.47	.47	.49	.40	
Mag. Est.	V	.26	.30	.37	.31	.39	.36	.02	.40	.40	.36	.40	.34	.33	
	L	.07	-.06	.03	.20	.41	.44	.05	.37	.35	.27	.36	.32	.16	.31
	T	.14	.29	.22	.20	.32	.32	.05	.30	.31	.34	.37	.12	.25	
Six-point (7)	V	.11	.09	.14	.31	.32	.29	.18	.25	.29	.29	.28	.30	.24	
	L	-.06	-.05	-.12	.23	.33	.29	.07	.31	.32	.33	.30	.30	.19	.30
	T	-.06	.14	-.01	.19	.30	.32	.14	.27	.33	.30	.29	.34	.21	
Six-point (8)	V	.20	.28	.28	.22	.26	.20	.03	.17	.22	.22	.21	.26	.21	
	L	.14	.06	.05	.20	.17	.26	.06	.16	.12	-.01	.10	.06	.11	.30
	T	.24	.28	.09	.24	.16	.19	-.02	.04	.12	.10	.11	.00	.13	

lation between the subjects' ratings and the total g(rms) of vibration recorded at each of the 17 segments of the ride. Although some of the correlation coefficients obtained for the five-point procedure are moderate, the correlations for the other procedures are rather low. Included among these rather low correlations are those between the ratings and the total g(rms) recorded at each test segment.

The multiple correlation coefficients resulting from the multiple regression analyses are shown in table 3. The first column presents the predictor variables and the second column presents the multiple correlation coefficient based on that predictor variable plus the predictor variables listed above it. For comparison purposes, the simple correlation between each variable and the criterion measure is presented in the third column. It should be noted that these analyses were done in a step-wise fashion, so that the predictor variables are ordered by the amount of additional variability in the ratings accounted for by that predictor variable. Thus the first variable listed accounts for the most variability in ratings. The second predictor variable listed accounts for more of the remaining variability in the ratings than any of the remaining predictor variables. In this technique, variables continue to be listed only so long as they produce a significant increase in the multiple correlation coefficient.

The multiple correlation coefficient obtained for each of the rides is considerably greater than any of the individual or simple measures of correlation between vibrations and ratings given in table 2. These multiple correlations probably represent a better estimate of the relation between the vibrations and the ratings obtained with the various rating procedures. The highest correlation was found with the five-point category-estimation scale, .61, and the lowest occurred with the six-point scale, .38, and .39.

The most interesting feature of the regression analysis is the ordering of the variables. There is no consistent pattern

Table 3. Table of multiple regression analyses.

Five-point			Mag. Est.			Six-point (7)			Six-point (8)		
Var.	Mult. r	Simp. r	Var.	Mult. r	Simp. r	Var.	Mult. r	Simp. r	Var.	Mult. r	Simp. r
L 9-11	.56	.56	L 11-13	.44	.44	T 23-25	.34	.34	T 3-5	.28	.28
V 7-9	.57	.51	L 5-7	.45	.03	T 17-19	.35	.33	L 11-13	.31	.26
V 1-3	.58	.10	V 13-15	.46	.02	V 3-5	.35	.09	L 19-21	.32	.01
L 21-23	.59	.48	T 3-5	.48	.29	V 9-11	.36	.32	T 13-15	.33	-.02
L 13-15	.60	.01	L 19-21	.48	.27	T 5-7	.36	-.01	T 23-25	.34	.003
L 1-3	.61	.09	V 7-9	.49	.31	L 9-11	.37	.33	T 9-11	.35	.16
V 9-11	.61	.48	L 15-17	.49	.37	T 13-15	.37	.14	V 5-7	.37	.27
V 13-15	.61	-.09	L 21-23	.50	.36	V 5-7	.37	.14	L 21-23	.38	.11
L 11-13	.61	.25	V 15-17	.50	.30	L 13-15	.38	.07	T 1-3	.38	.23
V 23-25	.61	.50	T 15-17	.50	[illegible]	V 17-19	.38	.29	T 7-9	.38	.23
L 3-5	.61	.05	T 9-11	.50	.32	T 7-9	.38	.19	V 7-9	.39	.22
V 3-5	.61	.32				L 3-5	.38	-.05	V 11-13	.39	.21
T 1-3	.61	.40				L 5-7	.38	-.12			
V 19-21	.61	.52				L 15-17	.38	.31			
L 17-19	.61	.47									

apparent across the rides, with respect to axis or frequency. In fact, none of the 36 predictor variables is used in all four analyses and only three were used in three of the four analyses. It would appear that if any axis or frequency of vibration was particularly important to ride quality that this would be revealed by some consistent pattern in the regression analyses. It is possible that this lack of pattern may be due to the differences among the 36 physical parameters in amount and variability of g(rms) produced by the bus across the several rides. Equating for this ride variability could possibly make a pattern in the regression analyses more obvious. At present, however, the regression analysis does not reveal a combination of frequencies or axes that are singularly important to ride quality on a bus.

Factor Analysis

Factor analysis using the 36 physical vibration measurements taken from each of the 17 segments on each of the four rides was performed in an attempt to identify groups, frequencies, axes, or combinations of these that were varying together and therefore could have been acting together in their effect on the ratings. The results of this analysis are shown in table 4; this table presents the factor loading of each of the 36 measures on the five significant factors that were found. The first factor has been identified as a *general factor* consisting primarily of effects from the frequencies below 11 Hz, but excluding vertical vibration below 3 Hz; also, this factor included effects from frequencies above 17 Hz in the vertical and transverse axes. The variables excluded from the first factor are the middle frequencies between 11 and 17 Hz. The second factor, identified as a *high frequency longitudinal factor*, has loadings that were mostly in the longitudinal axis above 7 Hz. The third factor is defined by frequencies above 7 Hz in the vertical and lateral axes, and has been identified tentatively as a *high frequency vertical-lateral factor*, although some of the higher frequences also contribute to the first

Table 4. Table of results of the factor analysis.

Frequency	Axis	Factors 1	2	3	4	5	Communality
1 - 3	V	.07	.01	.08	.02	.75	.57
	L	.76	-.03	.01	.00	.23	.64
	T	.91	.07	.27	.19	.07	.95
3 - 5	V	.51	.14	.17	.09	.75	.88
	L	.67	.03	-.05	-.15	.10	.49
	T	.88	.13	.20	.05	.21	.88
5 - 7	V	.53	.27	.20	.08	.52	.67
	L	.67	.05	.23	.40	.00	.66
	T	.81	.08	.25	.23	.03	.79
7 - 9	V	.76	.32	.25	.13	.21	.81
	L	.73	.30	.13	.27	.14	.73
	T	.80	.11	.36	.10	.05	.79
9 - 11	V	.81	.21	.46	.05	.14	.94
	L	.71	.49	.22	.04	.20	.83
	T	.62	.33	.49	-.01	.09	.75
11 - 13	V	.44	.02	.78	.14	.07	.82
	L	.11	.66	.14	.26	.40	.69
	T	.47	.45	.63	.10	.12	.84
13 - 15	V	.45	.09	.38	.72	.04	.87
	L	.00	.43	.01	.69	.15	.68
	T	.50	.15	.51	.58	.01	.87
15 - 17	V	.36	.03	.86	.15	.24	.94
	L	.07	.87	.16	.14	.14	.82
	T	.08	-.07	.81	.06	.11	.68
17 - 19	V	.71	.27	.49	.16	.23	.89
	L	-.05	.94	.05	-.03	.07	.89
	T	.55	.39	.47	.18	-.03	.71
19 - 21	V	.82	.26	.38	.21	.06	.93
	L	.09	.88	-.05	-.01	-.06	.78
	T	.38	.66	.51	.09	-.01	.84
21 - 23	V	.64	.49	.29	.17	.27	.84
	L	.29	.86	.01	.17	.00	.85
	T	.56	.55	.53	.11	-.04	.91
23 - 25	V	.83	.19	.40	.24	.02	.94
	L	.34	.80	-.02	.14	.00	.77
	T	.71	.34	.49	.18	-.07	.89

factor as well. Frequencies from all three axes of the 13 to 15 Hz band define the fourth factor, a specific factor for that frequency range. The last factor is also a specific factor defined by the vertical axis below 7 Hz.

Thus, in addition to a general level of vibration which involves all of the axes and most of the frequencies, there are four other patterns of vibration apparent in the bus-ride physical measures: (1) middle and high frequency longitudinal vibration; (b) middle and high frequency vibration in the other two axes; (c) vibration in all three axes between 13 and 15 Hz; and (d) low frequency vertical vibration. Inspection of table 1 shows that the mean g(rms) for these combinations of axes and frequencies are relatively high, except for high frequency vertical and transverse vibration. Inspection of table 2 shows that except for the fifth factor, moderately high correlations are present between the ratings and many of the variables that have high factor loadings on the other four factors.

DISCUSSION

The results of these analyses show that a moderately strong relation exists between the amount of vibration g(rms) measured on the buses and the ratings of ride quality by the subjects. Also, the five-point category-estimation procedure produced the strongest relationships. While it might have been useful to have had data using procedures with more categories, the data obtained with the six-point procedure failed to yield as strong relationships as did the five-point procedure, making somewhat doubtful the proposition that a procedure with more categories would have been more successful.

The most striking result of these analyses was the failure to find evidence from the multiple regression analysis that any particular combination of physical measures was consistently important in accounting for ratings of ride quality. Perhaps the distribution of energy among the 36 vibration measures was such as

to prevent the most important vibrations from showing effects. Going back to Jacklin and Liddell (1933), it is well established in the literature that both frequency and amplitude of vibration differentially affect ratings of ride quality. However, that the bus produces more energy in some frequencies than others should have the effect of shifting greater importance in determining ride quality ratings to those frequencies with the greatest vibration energy. That the obtained effect is one in which no frequency or axis is particularly important is puzzling, and suggests the wisdom of seeking another explanation of the results. While a number of variables could be responsible for the lack of an apparent pattern--the characteristics of the road course, the rating procedures, the degree of control present when the ratings were being taken, etc.--one that should not be overlooked is the manner of analyzing the physical data. While sophisticated techniques for data reduction permit analyzing all of the vibrations into the amount of energy in the various frequency components, it is doubtful that the sensory system of a subject is capable of a similar analysis of the vibrations they experience, especially when that frequency component may last for only a fraction of a second before changing through a myriad of other frequencies. Perhaps an analysis of not only frequency and accumulated amplitude for each stimulus, but also both the frequency count and duration of each frequency and amplitude would lead to a more meaningful description of the vibration stimulus.

The factor analysis of the data is useful in that it permits analysis of the stimuli experienced by the subjects into a general component consisting of a wide variety of vibrations and four specific components and thus gives a better picture of the stimuli presented to the subjects. Since all but one of these factors seem related to ratings of ride quality, the factor analysis approach was unsuccessful in identifying a limited group of variables primarily responsible for the ride quality of the bus.

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APPENDIX B

A COMPARISON OF SUBJECTIVE RATINGS OF RIDE QUALITY OBTAINED FROM FIELD TESTS USING TRANSIT BUSES TO RATINGS OF SIMULATIONS OF THE FIELD TESTS PRODUCED BY PRQA

The purpose of this research was to determine the extent to which comparable ratings of ride quality to those found during field tests could be found using the Passenger Ride Quality Apparatus (PRQA) to simulate the field tests. The data from previous research (Mikulka, Kirby, and Simmons, 1973), employing field tests with transit buses was chosen for simulation by PRQA for this comparison.

The prior research using buses showed that subjects' ratings of comfort during a trip on a bus were significantly correlated with vibrations measured during the trip. Nine different bus rides over the same course were employed to study subjective ratings produced by different scaling procedures. Seventeen segments of the ride, lasting approximately 15 seconds each, were selected for rating to cover the range of ride quality conditions found on the road course, and each subject rated each of the segments. For the first study reported in this paper the data from a two-point category-estimation or binary procedure was chosen. For the binary scale, the mean correlation between the various physical parameters and the proportion of subjects rating each segment as "unsatisfactory" was found to be .53 (median = .59).

The purpose of the present research was to simulate the actual bus rides used in the previous research by employing tapes of vibrations measured on those bus rides and the PRQA to reproduce those vibrations. As a result new subjects could be exposed to the same vibrations experienced on the buses and asked to rate them with the same rating procedures used previously on the buses. If the correlations between the physical parameters of the vibrations and the subjective ratings found using the PRQA were found to be comparable to those found in the field tests, some light

would be shed on the question of the extent to which PRQA can simulate field test situations. This study is necessarily limited since PRQA can produce vibrations in only two linear axes simultaneously, and for this study the vibrations in the longitudinal axis were omitted.

TWO-POINT CATEGORY-ESTIMATION PROCEDURE

This test used vibrations recorded on the bus test in which the two-point category-estimation procedure was used (Ride 3).

Method

Subjects.- Eighteen undergraduate students recruited from the student body of Old Dominion University were recruited from a larger list of volunteers who had been medically screened and approved by the NASA-Langley Research Center.

Apparatus.- The apparatus used in this research was the PRQA located at NASA-Langley Research Center. This apparatus, designed to simulate a passenger aircraft, can present subjects with whole-body vibrations of various frequencies, amplitudes, and wave forms in either the vertical, lateral, or roll axes separately or simultaneously. For this experiment the PRQA was equipped with two rows of bus seats, each comfortably accommodating two subjects. Additional details of the PRQA can be obtained from Clevenson and Leatherwood (1972) and Stephens and Clevenson (1973).

Procedure.- The subjects were transported to the Langley Research Center from Old Dominion University, a distance of approximately 25 miles, in a late-model, nine-passenger station wagon. Upon arriving at Langley the subjects were taken to a conference room adjacent to the room housing the PRQA. Here the subjects were given their instructions regarding the experiment and appropriate safety procedures. The subjects were then seated in the PRQA and asked to fasten their seat belts.

Throughout the testing, two-way audio communication was maintained with the subjects, and the subjects were also continually observed through a one-way mirror, as part of the safety procedures.

At the beginning of each test stimulus the subjects were told "Begin" and at the end of the stimulus presentation the subjects were told "Rate." Each trial consisted of 5 seconds for the stimulus to reach the appropriate level, 15 seconds of stimulus, and 15 seconds between trials. The stimuli were the segments of Ride 3.

The subjects rated each of the segments as "satisfactory" or "unsatisfactory." The 17 segments were first presented in the order in which they occurred on the bus, then in random order, and finally in reverse order. Thus each of the stimuli was presented to the subjects three times.

RESULTS

Correlation of PRQA Subjective Ratings with Bus Ride 3 Output Vibrations

The subjective ratings of the PRQA subjects were correlated with the vibration energy inputs from Bus Ride 3 for the lateral and vertical axes only. Given that the average subjective correlation on the original field bus ride was .53, it would be expected that if the PRQA simulated the original ride environment that the resultant correlations would approximate this level. Table 1 shows the correlations of subjective responses with lateral and vertical PSDs. A comparison of these data with those from the original Bus Ride 3 show that the present results are similar to the pattern found for the field test subjects.

Relationship Between Subjective Ratings on Bus and PRQA

Since the vibration data from the bus ride was used as input to the PRQA, a comparison of the vibration ratings from the bus ride subjects with the PRQA subjects should assess the ability of the PRQA to reproduce field data. However, before the data are

Table 1. Correlation coefficients of subjective responses on the PRQA with the PSD levels from the bus ride in the lateral and vertical axes.

Hz		Axes: Lateral	Axes: Vertical
1-3		.26	.32
3-5		.61**	.57*
5-7		.62**	.79**
7-9		.23	[illegible]
9-11		.44	[illegible]
11-13		.66**	.66**
13-15		.31	.37
15-17		.43	.53*
17-19		.66**	.67**
19-21		.52*	.61**
21-23		.43	.66**
23-25		.09	.74**
	Mean	.44	.58

* Significant beyond .05 level.
** Significant beyond .01 level.

presented it must be stressed that the original bus vibration-subjective correlations, whether PSDs for each Hz bandwidth or whether overall RMSs were used, produced Pearson correlations in the range of .32 to .76 with a mean of .55. With this as a reference the correlations of the bus ratings with the three PRQA orders are shown in table 2.

This pattern of correlations between the PRQA simulations and the field subjective ratings suggests that the PRQA simulator does a reasonably good job of replicating field data. Simply, the pattern of subjective ratings on the bus ride corresponds well with that observed for the subjects on the simulator.

Table 2. Correlation coefficients between ratings on the bus and rating on PRQA.

Variables	r
Bus and PRQA-forward	.49*
Bus and PRQA-random	.58**
Bus and PRQA-reverse	.48*

* Significant beyond .05 level.
** Significant beyond .025 level.

Order of Presentation of Segments

Pearson product-moment correlations were computed on the percent of subjects rating each segment as unsatisfactory for all combinations of the three presentation orders. The correlations are shown below in table 3.

Table 3. Correlation coefficients between different orders of presentation of the stimuli.

	r
Forward and Random	.86*
Forward and Reverse	.85*
Random and Reverse	.90*

* Significant beyond the .01 level.

These data indicate that the subjects can reliably rate the 17 ride segments regardless of the order of presentation. Further, if the absolute percentages of unsatisfactory ratings are examined the ra[illegible] for the three orders are very similar. Examination of figure [illegible] will show that subjective responses for the three different orders are apparently predominantly determined by the absolute

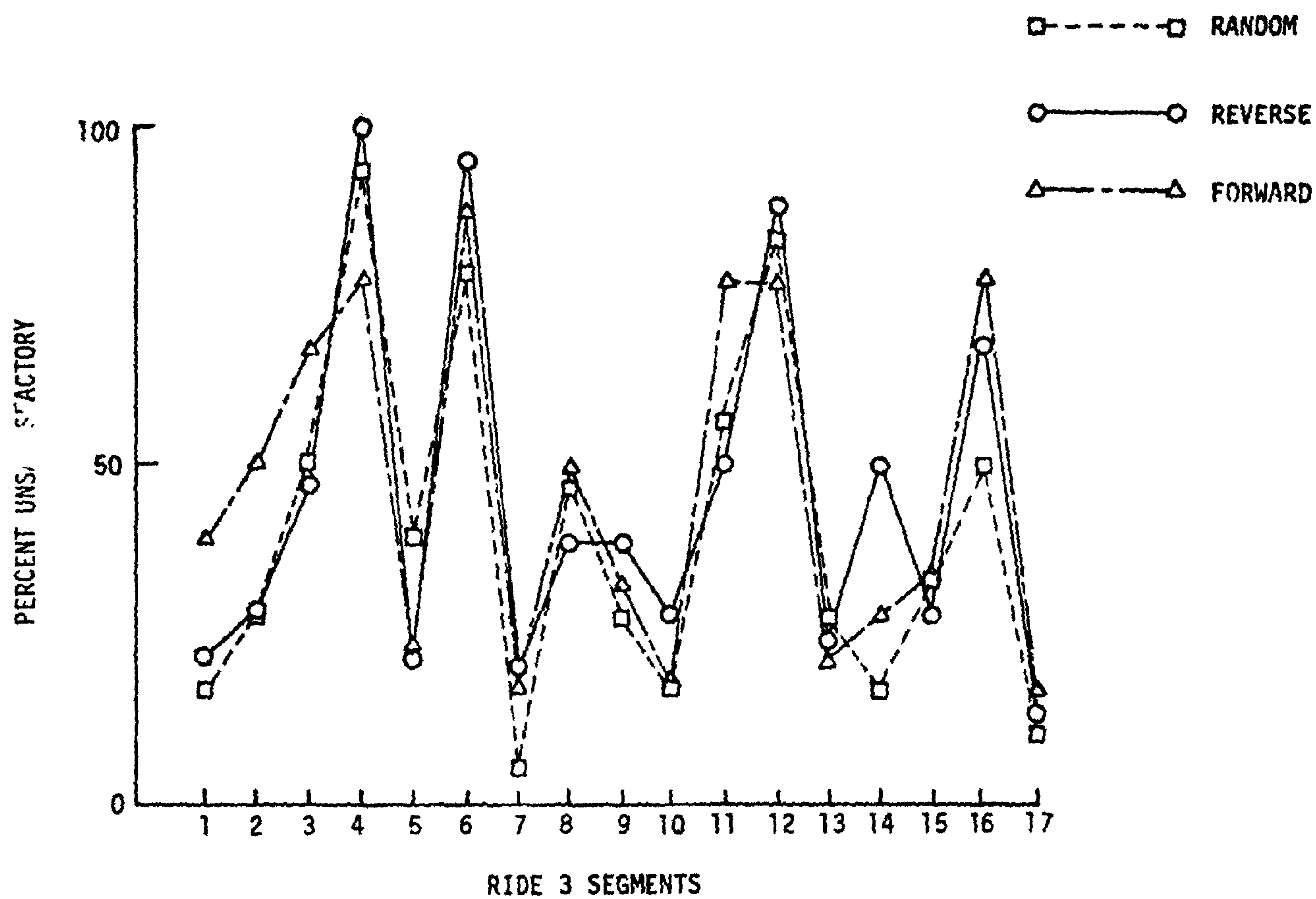

Figure 1. Percent unsatisfactory ratings for each ride segment for each order of presentation.

vibration levels and not the order of occurrence in the sequence of segments. This consistency may reflect the fact that subjects come to a vibration situation with a well established set of norms and these result in consistent judgements of comfort.

FIVE-POINT CATEGORY ESTIMATION AND MAGNITUDE ESTIMATION PROCEDURES

Upon completion of the simulations by PRQA of the bus tests in which the two-point category estimation procedure was used, additional tests were conducted to extend the validation to other bus rides and to two other rating procedures--a five-point category-estimation procedure and a magnitude estimation procedure.

Method

Subjects.- Thirty-two undergraduate students from the student body of Old Dominion University were recruited from a larger list of volunteers who had been medically screened and approved by NASA-Langley Research Center.

Apparatus.- The apparatus used in this research, PRQA, was the same as used in the previous tests.

Procedure.- The subjects were tested using the same procedures as were used in the previous tests except for variations imposed by the use of the two different rating procedures and the use of vibration stimuli recorded from the bus rides in which these two rating procedures were employed. Sixteen of the subjects were tested using the five-point category estimation procedure, and the remaining 16 subjects used the magnitude estimation procedure.

The details of instructions for the two rating procedures are given in the earlier report of the bus tests (Mikulka, Kirby, and Simmons, 1973). For the five-point rating procedure, "5" was assigned a ride that was "excellent," "4" to one that was "good," "3" to one that was "fair," "2" to one that was "poor," and "1" to one that was unacceptable."

Our subjects were run simultaneously on the PRQA with each subject rating the vibration recorded from each of the 17 segments recorded on the original tests with buses. The vibrations recorded from the bus ride in which the five-point category-estimation procedure was used (Ride 2) was run first, and then followed by the recordings from the bus ride in which the magnitude estimation procedure was used (Ride 4). A one-minute rest was interposed between the two bus simulations; the total time required to run the two simulations was approximately 30 minutes.

RESULTS

Correlation of Vibrations Recorded on the Bus to Those Recorded on PRQA

Before examining the relation between the subjective ratings and ride quality as simulated by PRQA, an examination of the correlation between the vibrations recorded on the buses (the PRQA inputs) and the vibrations recorded on the PRQA (the PRQA outputs) was made. These vibration data were analyzed using a power spectrum analysis to determine the g(rms) in each 2-Hz bandwidth between 1 Hz and 25 Hz for the vertical and lateral axes.

Table 4 shows for each bus ride the correlation between the PRQA input and the PRQA output for each frequency band in each of the two axes of vibration. Examination of these data indicate that the vertical input was well reproduced for both rides, with the exception of the 1 to 3 Hz band for the first ride. The correlations for the lateral axis were strong for most of the bandwidths, but weakened at the two highest bandwidths, between 21 and 25 Hz. In general these findings support the conclusion that the PRQA replicated the pattern of inputs well, and therefore, is presumed to be a reasonable simulation of the vibrations recorded in the field.

Table 4. Pearson correlation coefficients between PRQA input and output PSDs for simulations of Bus Rides 2 and 4.

Hz	Ride 2 Simulation Vertical	Ride 2 Simulation Lateral	Ride 4 Simulation Vertical	Ride 4 Simulation Lateral
1-3	.42*	.94	.99	.95
3-5	.99	.94	.99	.90
5-7	.96	.94	.99	.98
7-9	.87	.80	.99	.92
9-11	.94	.87	.93	.99
11-13	.99	.96	.99	.99
13-15	.99	.98	.97	.96
15-17	.99	.66	.95	.99
17-19	.95	.79	.94	.91
19-21	.99	.94	.98	.92
21-23	.96	.79	.96	.89
23-25	.97	.60	.95	.71

*All correlations are significant at beyond .01 level except this one at .05 level.

Correlation Between Vibration and Subjective Ratings of Ride Quality

Table 5 shows the correlation coefficients for each subject between the subjective ratings and the g(rms) for each axis on each of the two ride simulations. These correlations are highly significant and follow the pattern of correlations found for the original bus rides. For some reason, with both rating procedures the correlations for Ride 4 were somewhat greater than for Ride 2. There does not appear to be any appreciable difference between the correlations obtained for the two axes on either ride or with either rating procedure.

Table 5. Correlation of subjective ratings with total rms in the vertical and lateral axes.

Five-point Category Estimation Procedure

	Ride 2		Ride 4	
Subject	Vertical	Lateral	Vertical	Lateral
1	.72	.66	.82	.76
2	.79	78	.84	.74
3	.64	.66	.84	.78
4	.71	.69	.79	.[illegible]4
5	-.02	-.20	.01	-.26
6	.60	.61	.57	.62
7	.78	.66	.70	.69
8	.84	.67	.80	.86
9	.84	.79	.66	.61
10	.51	.65	.78	.77
11	.39	.53	.10	.11
12	.61	.68	.76	.71
13	.66	.79	.86	.72
14	.69	.77	.82	.77
15	.62	.74	.71	.65
16	.49	.62	.77	.70
Means	.62	.64	.68	.63

Magnitude Estimation Procedure

	Ride 2		Ride 4	
	Vertical	Lateral	Vertical	Lateral
17	.43	.59	.46	.46
18	.66	.73	.78	.75
19	.40	.65	.82	.71
20	.54	.67	.87	.78
21	.72	.76	.81	.82
22	.80	.79	.88	.86
23	.51	.64	.85	.86
24	.66	.73	.80	.66
25	.63	.66	.84	.75
26	.83	.89	.89	.72
27	.63	.69	.68	.66
28	.63	.77	.62	.60
29	.51	.54	.84	.76
30	.66	.60	.85	.76
31	.41	.52	.46	.48
32	.52	.63	.63	.71
Means	.60	.68	.76	.71

It is of some interest to note that although for all 16 subjects using the magnitude estimation procedure and for 14 of those using the five-point estimation procedure the correlations between ratings and vibrations are quite high, two subjects who used the five-point procedure (subjects 5 and 11) deviate markedly from this pattern. At this point it is difficult to account for these discrepancies; it is possible that these subjects (1) failed to understand the use of the scale, (2) made some error in recording their responses, or (3) were not sufficiently motivated to properly use the rating instrument.

CONCLUSIONS

The findings of the present research indicate that the PRQA readily simulated the vibration environment found on public transportation buses. This conclusion is based on several data sources. First, the inhouse NASA data which indicates that the PRQA reliably replicates physical inputs in the range covered by the present bus data. Further, this is supported by the extremely high correlations between PRQA input and output over the 12 Hz bandwidths for both the lateral and vertical axes, using simulations of three different bus rides. Second, the significant correlations between subjective ratings on the bus (Ride 3) and ratings of PRQA subjects to the same vibration segments. This indicates that even though a number of major differences exist between the field run and the PRQA simulation (e.g., time of run, time between segments, a "real" bus ride, scenery, etc.), the subjects still show a good agreement in relative ratings of comfort.

Third, using the same vibration outputs from the bus rides a highly significant pattern of correlations emerged between subject ratings using three rating procedures and vibrations produced by PRQA. In essence, subjects on the PRQA can readily evaluate vibration and, as vibration inputs increase, subjective ratings of discomfort increase.

Fourth, the subjective ratings of ride comfort for a given segment appear to be a function of the absolute energy in that segment, and not on the contextual order in which segments follow each other. In fact, whether a given ride is reversed or randomly presented the subjective ratings show a remarkable agreement with the "normal" forward order.

REFERENCE

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